Superconductor Development in Europe

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CEA-DSM-DAPNIA-STCM

VLHC Magnet Workshop
24-26 May 2000

Contents

- NbTI
- Nb_3Sn
  - ITER
  - CEA/Saclay-Alstom
  - INFN/Milan-Europa Metalli
  - PIT in the Netherlands
- HTS

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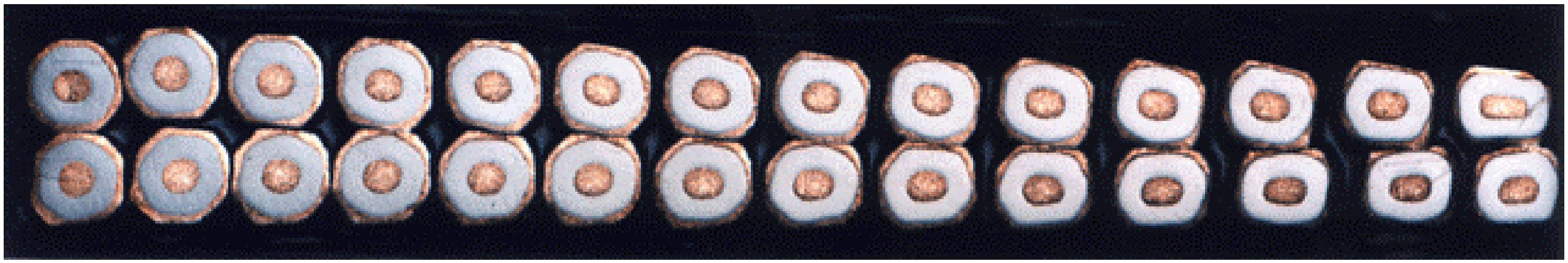
NbTi Production

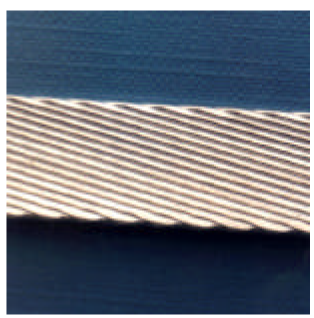
- NbTi production is mainly driven by LHC: 474 t (2370 km) of inner cable, 736 t (4025 + 575 km) of outer + quad. cable
- Requires ~50% increase in wire and cable production over the next five years (yearly production will become ~1/3 LHC, 1/3 IRM and 1/3 other)

LHC Inner Cable



STRAND CHARACTERISTICS

Diameter: 1.065 ± 0.0025 mm
$1.6 \le$ Cu/Sc ≤ 1.7
Filament diameter : ~7 µm
Number of filaments: ~8900
Stabrite coating (between 0.4 and 0.6 µm)



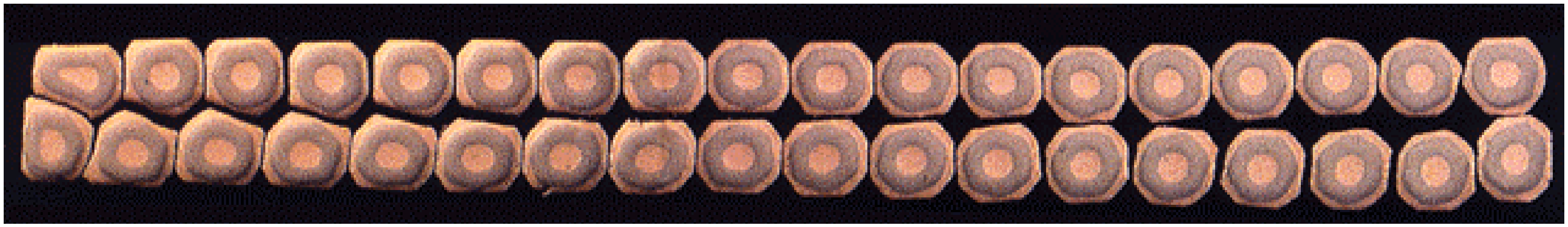
CABLE CHARACTERISTICS

Rutherford-type cable
28 strands
Thick-edge thickness: 2.064 ± 0.006 mm
Thin-edge thickness: 1.736 ± 0.006 mm
Width: 15.1 + 0/-0.02 mm
Critical Current (4.2 K, 7 T): $\ge$ 14140 A
Critical Current (1.9 K, 10 T): $\ge$ 13750 A

Courtesy

ALSTOM

LHC Outer Cable



<u>STRAND CHARACTERISTICS</u>

Diameter : 0.8250 ± 0.0025 mm
1.9 £ Cu/Sc £ 2.0
Filament diameter: ~6 µm
Number of filament: ~6400
Stabrite coating (between 0.4 and 0.6 µm)

<u>CABLE CHARACTERISTICS</u>

Rutherford-type cable
36 strands
Thick-edge thickness: 1.598 ± 0.006 mm
Thin-edge thickness: 1.362 ± 0.006 mm
Width: 15.1 + 0/- 0.02 mm
Critical Current (4.2 K, 6 T): ³ 13230 A
Critical Current (1.9 K, 9 T): ³ 12960 A

Courtesy

ALSTOM

Sharing of LHC Production

Manufacturer	Process	Inner	Outer	Cabling
Alstom (France)	Single Stacking	5/8 (296 t)	3/8 (276 t)	In house
Europa Metalli (Italy)	Double Stacking		3/8 (276 t)	Brugg (Switzerland)
Vac (Germany)	Double Stacking	3/8 (178 t)		Brugg (Switzerland)
IGC (USA)	Single Stacking		1/8 (92 t)	NEEW
Furukawa (Japan)	Single Stacking		1/8 (92 t)	In house

Status of LHC Production

- Contracts signed during second semester of 1998
- Production is gearing up at various manufacturers
- First 45 unit batches of inner wires (28x460 m) and first 31 unit batches of outer wires (36x750 m) ready to be cabled
- Production to be completed by 2004

LHC Production at ALSTOM

Clean room for billet assembly

Drawing bench

Cabling machine

Tyical Results of LHC Production (after L. Oberli)

- Critical current on virgin wires
  - Inner: J_c (4.2 K, 7 T) » 1550-1600 A/mm^2
  - Outer: J_c (4.2 K, 6 T) » 2300 A/mm^2
- Cabling degradation between 2 and 3%

Main challenges of LHC Production (after G. Grünblatt)

- Control of Cu-to-NbTi ratio (±0.03 from billet to billet)
- Control of crossover resistances (15 to 20 mW for inner cable and 30 to 40 mW for outer cable): stabrite (SnAg) coating + heat treatment on final cable
- No cold welds allowed

Wire Short Sample Tests

- It is foreseen to perform ~30 000 wire short sample tests at CERN

(Bldg. 163 at CERN; courtesy A. Verweij)

Cable Short Sample Tests

- It is foreseen to perform ~3000 cable short sample tests at BNL and ~1000 tests at CERN

(9.5-T, 30-kA cable test facility at CERN; courtesy A. Verweij)

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ITER Production

- The production of Nb_3Sn wires has been fueled in the 90's by the ITER program, which required two different wire types:

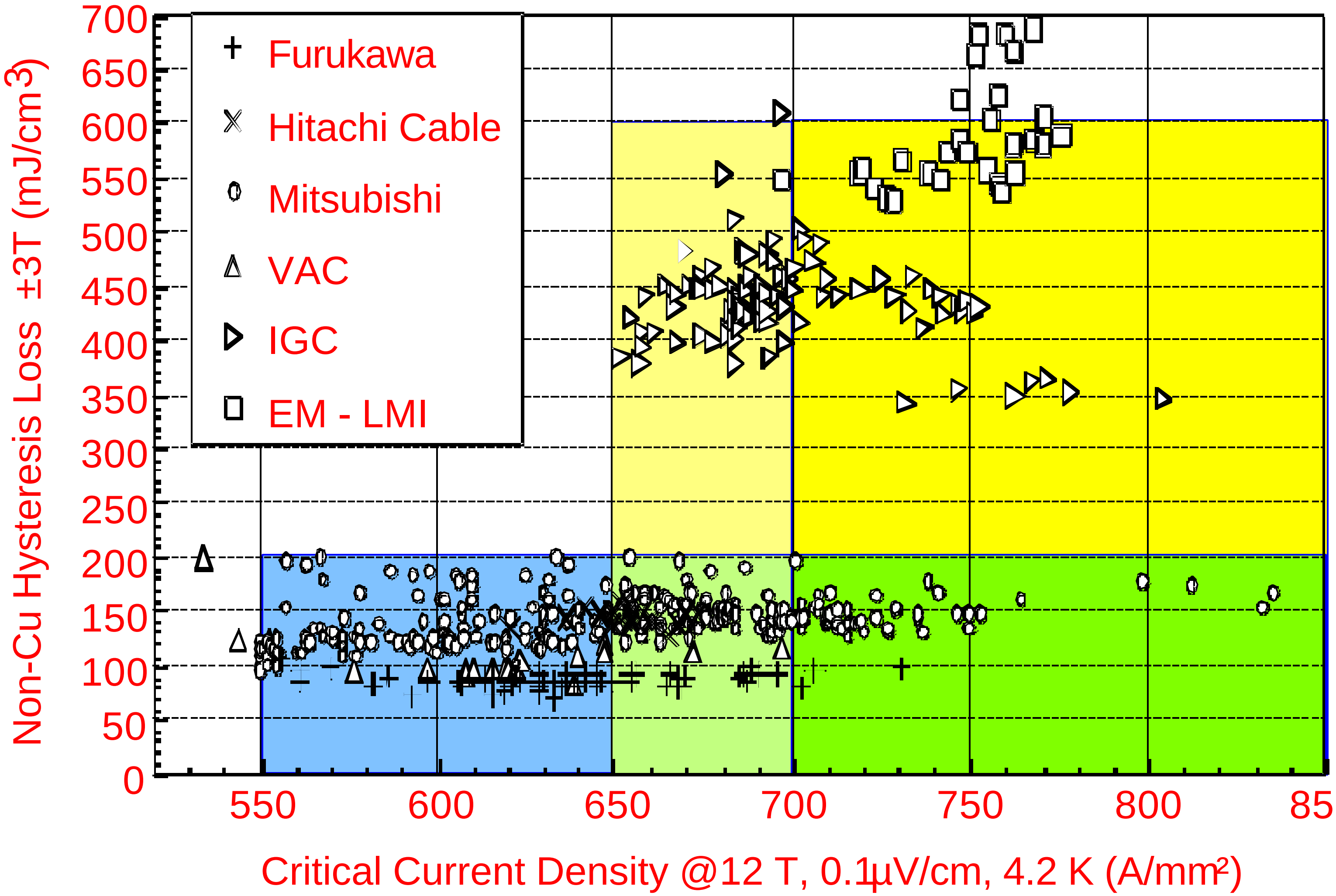
Type	J_C at 4.2 K and 12 T (A/mm^2-non-Cu)	Hyst. Losses for a ± 3 T cycle (mJ/cm^3-non-Cu)	Quantity (tonnes)
High Perf. I	700	600	6.5
High Perf. II	550	200	16.5

ITER Production (Cont.)

- One Western European vendor (Europa Metalli in Italy) was qualified for HP1 production (along with IGC and TWCA in the USA)
- One western European vendor (Vac in Germany) and one Russian vendor (Bochvar Institute in Moscow) were qualified for HP2 production (along with Furukuwa, Hitachi and Mitsubishi in Japan)
- Bochvar did produce some small quantity that was OK, but had to stop because of the financial problems of the Russian Federation
- ITER wire production was completed in 1997

Results of ITER Production

(Courtesy P.J. Lee)



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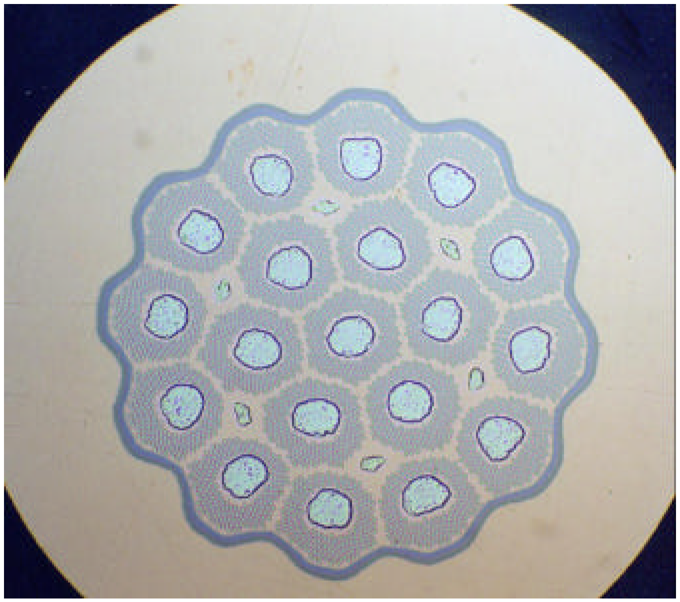
CEA/Saclay-Alstom Collaboration

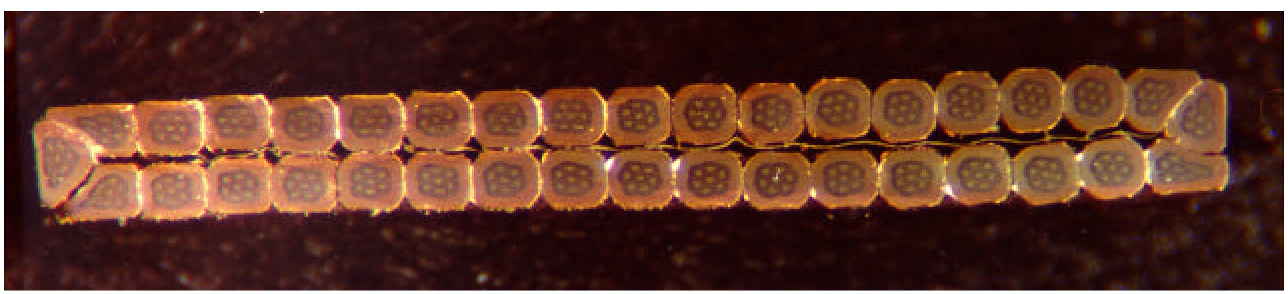
- CEA/DSM/DAPNIA/STCM has started in 1996 a collaboration with Alstom to develop high performance Nb_3Sn wire and cable and to build a short quadrupole magnet model
- The wire specification was inspired from ITER/HP1
- The program has been slow moving at CEA/Saclay because of lack of manpower, but Alstom has completed its share of the R&D work and is ready to start the production of the final cable lengths (5x60 m)

Nb_3Sn R&D at Alstom



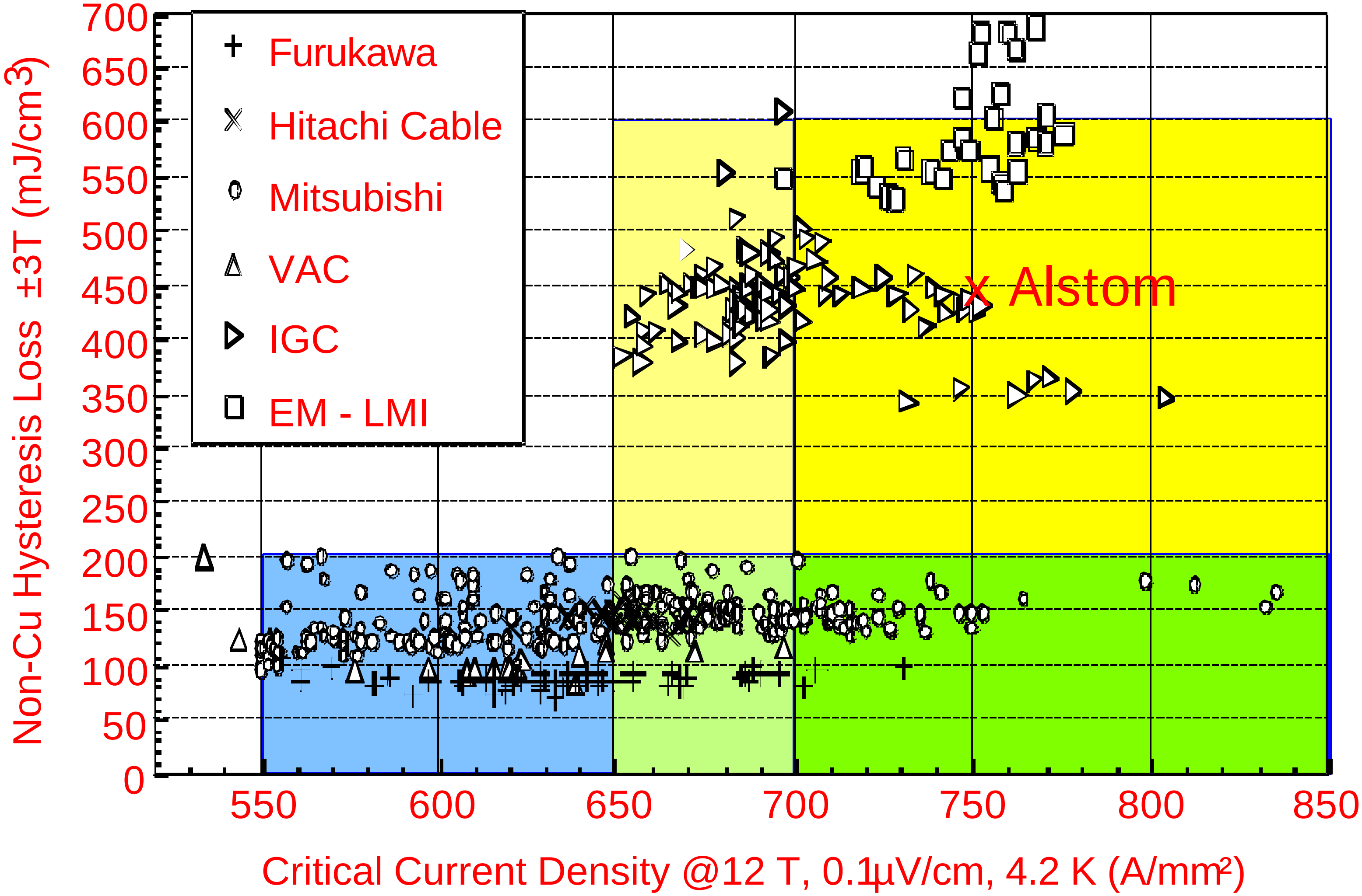
(Courtesy R. Otmani)

- The collaboration has enabled Alstom to produce:
  - an “internal-tin” Nb_3Sn wire with a J_C(non-Cu) of 750 A/mm² at 4.2 K and 12 T and an effective filament size of 18 mm
  - a Rutherford-type cable with a 25-mm-thick stainless steel (annealed 316L) core



Nb_3Sn R&D at Alstom (Cont.)

(Modified from P.J. Lee)



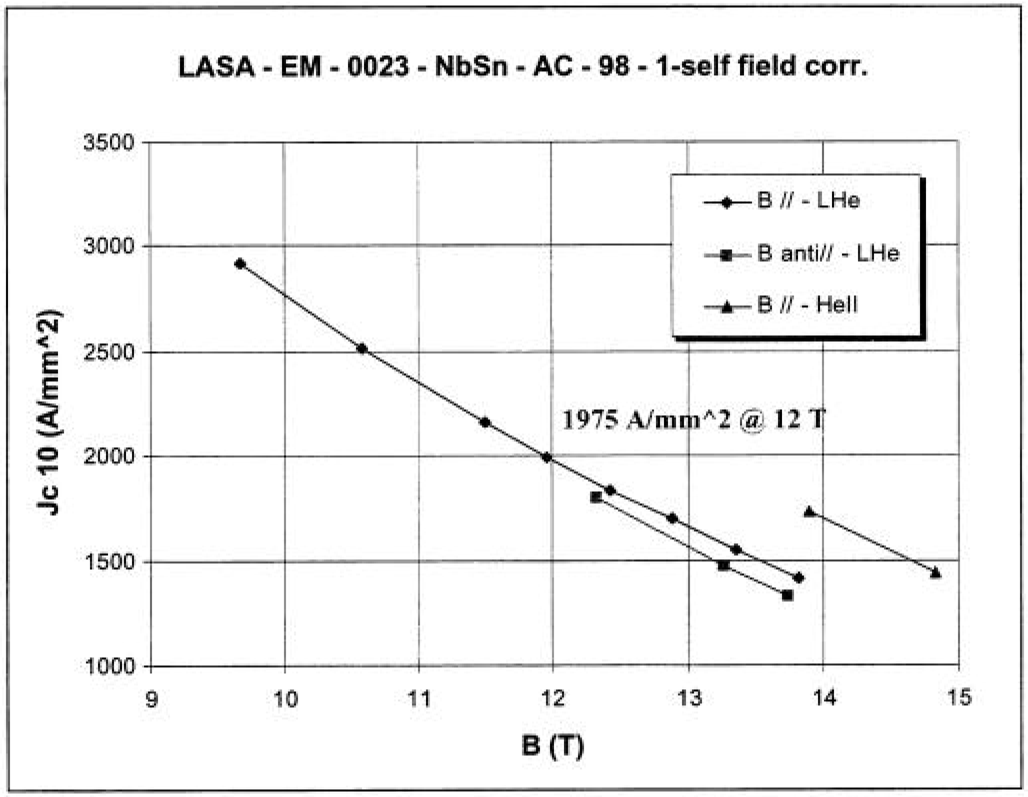
New CEA/Saclay-Alstom Collaboration

- Discussions are now underway with Alstom on a new collaboration to develop a wire with a J_C(non-Cu) of **2000 A/mm^2** at 4.2 K and 12 T and no specification on effective filament diameter (except that the wire should be stable against flux jump)
- Such wire could be used to build a second quadrupole magnet model that would be suitable for the final focusing of TESLA
(see my other talk at this workshop)

INFN/Milan-Europa Metalli Collaboration

- INFN/MILAN (LASA) has worked from 1995 to 1999 with Europa Metalli to develop Nb_3Sn wires for accelerator magnet applications
- The goal was to achieve a J_C(non-Cu) of 1800 A/mm^2 at 4.2 K and 12 T, to meet the requirements of a conceptual design for a large-aperture (70 mm), high-field-gradient (300 T/m) quadrupole magnet to upgrade the LHC inner triplets (see my other talk at this workshop)
- The program is presently on hold due to lack of funding

Nb_3Sn R&D at Europa Metalli



(Courtesy L. Rossi)

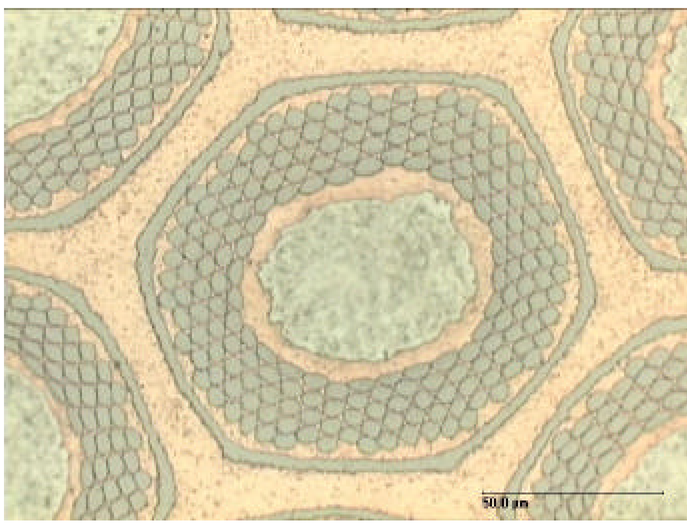
- **The best J_C values were obtained in 1998 for a 0.9 mm, "internal-tin" wire of the so-called "high-field" layout: ~1975 A/mm^2 at 4.2 K and 12 T (non-Cu)**

Nb_3Sn R&D at Europa Metalli (Cont.)

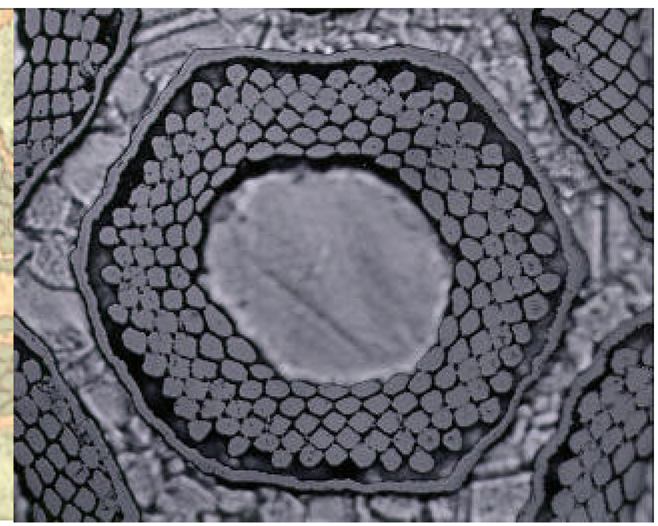
- **However the high-J_C wire exhibits signs of instability and the effective filament diameter is 108 μm**

Close-up view of a bundle ("high-field" layout)

Before HT



After HT



(Courtesy L. Rossi)

Nb_3Sn R&D at Europa Metalli (End)

- **Stable performances are obtained on lower J_C-wires of the so-called "3-sector" layout: 1450 to 1500 A/mm² at 4.2 K and 12 T (non-Cu) with 60 to 70 μm effective filament diameter**
- **I_C degradation for various types of Rutherford-type cables made from these strands has been measured to be between 10 and 20% (in the 12 to 14 T field range)**
- **I_C vs. tranverse stress measurements, performed at Twente University on a 1°-keystoned cable, showed less than 7% degradation at 200 MPa**

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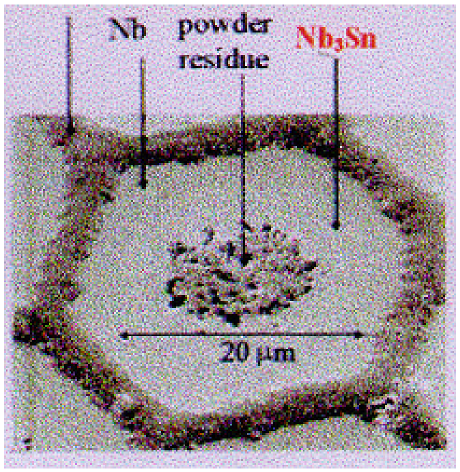
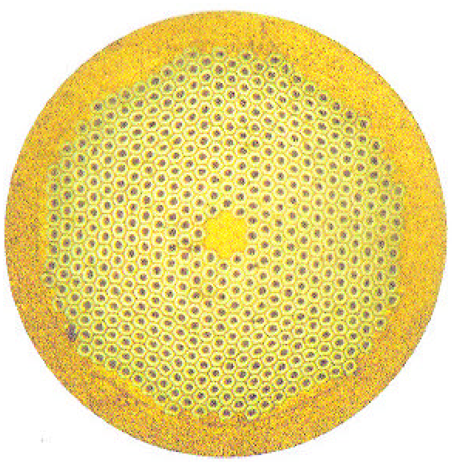
Nb_3Sn Developement at ECN

- In the 1980's, ECN (Netherlands Energy Research Foundation) has developed a quite successful "Powder In Tube" (PIT) process for Nb_3Sn wires
- The production was stopped in 1992 after internal restructuring at ECN and reorientation on core activities

ECN Process

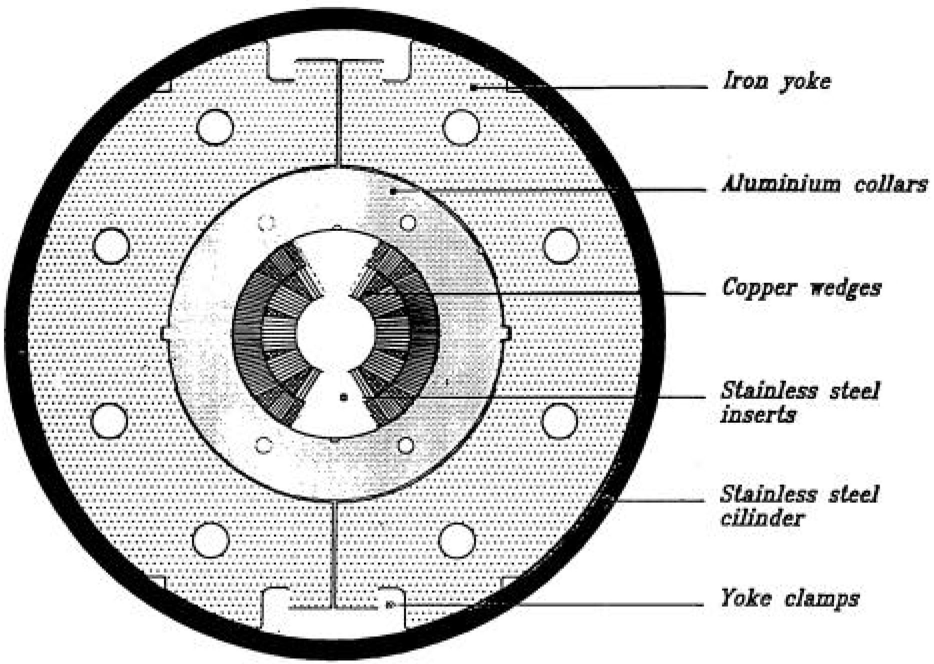


(Courtesy A. den Ouden)



- The ECN process is in two-steps:
  - – production of mono-filaments by compaction of Nb_2Sn and Sn powders inside a Cu liner fitted within Nb and Cu tubes
  - – stacking of hexagonally drawn-down mono-filaments inside a Cu can
- It only requires short heat treatment (<48 hours)

Best Results of ECN Process

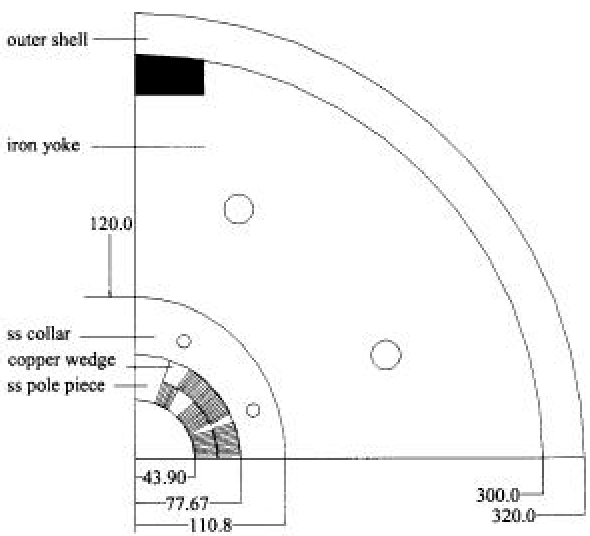


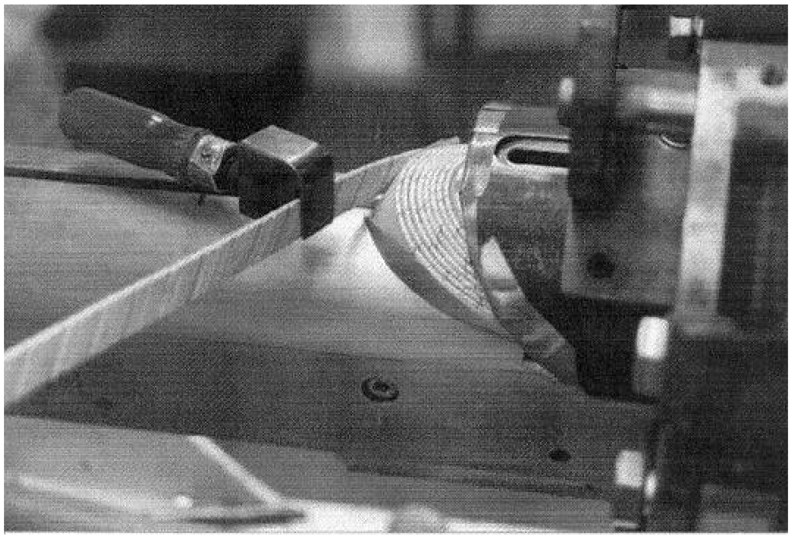
(Courtesy H.H.J. ten Kate)

- The best results were obtained in 1987 with a J_C(non-Cu) of 1600 A/mm² at 4.2 K and 11 T (physical filament diameter of 20 μm)
- ECN-processed wires were used in the dipole magnet model built at Twente University and tested at CERN in 1995, which reached 11.03 T on its first quench at 4.4 K

Nb_3Sn R&D at Twente University

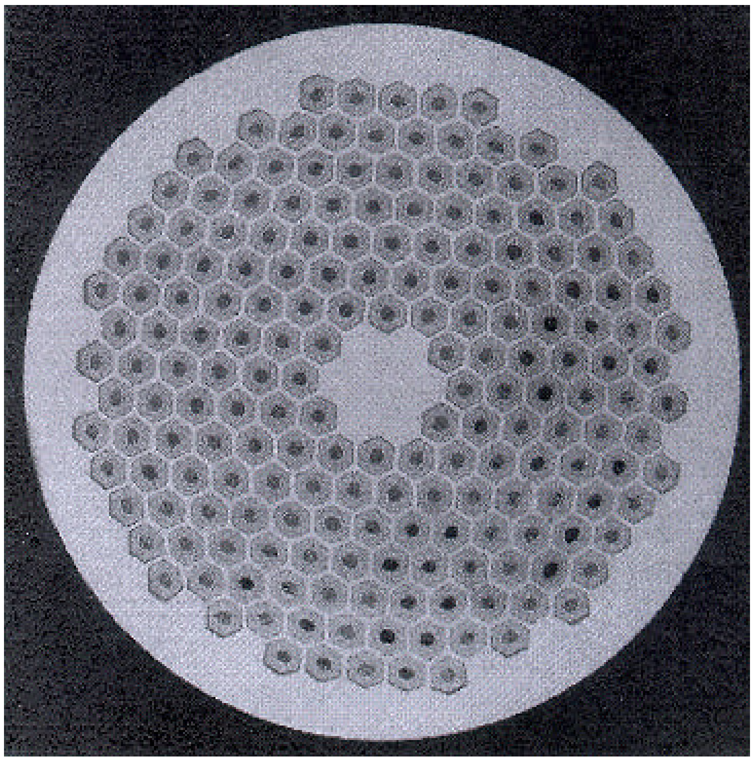
- Twente University has signed in 1998 a 3-year contract with CERN and NIKEF to build a 88-mm-aperture dipole magnet model, with a 10 T operating field (at 4.4 K), that could be used as a second-generation, beam-separation magnet in the LHC interaction regions. Test is scheduled at CERN in June 2001.





(Courtesy A. den Ouden)

Resumption of PIT production at ShapeMetal Innovation



(Courtesy A. den Ouden)

- With Twente University support, ShapeMetal Innovation (SMI) has acquired ECN tooling and know-how and has resumed PIT production in the late 1990’s
- SMI has recently achieved a record J_C(non-Cu) of 2300 A/mm² at 4.2 K et 12 T with an effective filament diameter of 50 μm (50 kg billet)

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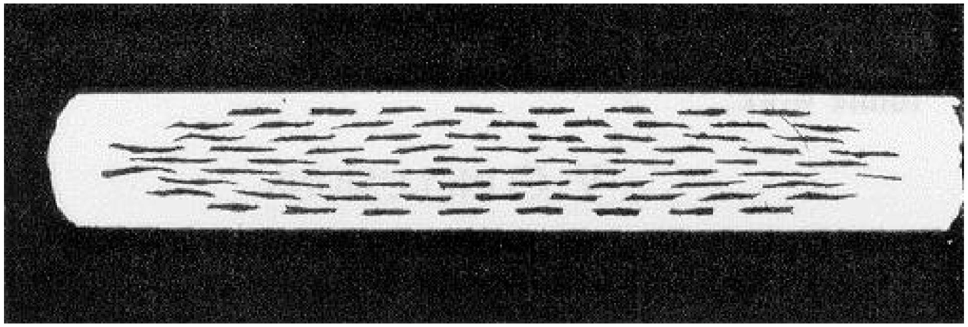
HTS Production in Europe

- **Bi-2212 Tape**
  - **Alcatel (France)**
- **Bi-2223 Tape**
  - **Nordic Superconductor Technologies (NST, Denmark)**
  - **Vacuumschmelze (Germany)**

Alcatel Production

- Alcatel has set up a production facility at Jeumont (France) for Bi-2212 PIT tape



(Courtesy P.F. Herrmann)

- Engineering J_C presently achieved are:
  - 775 A/mm^2 (at 4.2 K, self-field) on short lengths
  - 450 to 500 A/mm^2 (at 4.2 K, self-field) on kilometric lengths